IN THE SPECIFICATION:

Please replace the original specification with the enclosed substitute specification, in which the following amendments have been incorporated:

Please replace the paragraph beginning on page 1, line 4 with the following rewritten paragraph:

--This application is a divisional of U.S. Patent application, Serial No. 09/376,892 filed August 18, 1999 which is a continuation in part of U.S. Patent application, Serial No. 09/139,642 filed August 26, 1998, now abandoned.--

Please replace the paragraph beginning on page 1, line 6 with the following rewritten paragraph:

--The present invention relates to apparatus and methods for performing abrasive work on a work piece using an abrasive visco-elastic medium and, in particular, to apparatus and methods that impart a relative cyclic motion between the work piece and the medium to provide a separation between the medium and work piece during each cycle which separation is occupied by a fluid having a viscosity less than that of the visco-elastic medium and where the deformation of the medium is between 50 and 99%.--

Please replace the paragraph beginning on page 4, line 3 with the following rewritten paragraph:

--It is an object of the present invention to provide an improved abrasive machining process and apparatus in which a separation is maintained during the processing between the visco-elastic medium and portions of the work piece.--

Please replace the paragraph beginning on page 5, line 4 with the following rewritten paragraph:

--The present invention provides light grinding, deburring, radiussing, leveling and polishing of complex surfaces, and particularly three-dimensioned surfaces where surface detail requires working, and in repetitive working of multiple work pieces of complex form and shape. Generally, the apparatus of the present invention comprises a chamber which can be either closed or open for mounting a work piece. Preferably the new medium is fed to a gap,

the chamber preferably includes a plurality of inlets for feeding a visco-elastic abrasive medium therein. A drive is provided for imparting relative motion between the work piece and the visco-elastic medium by contacting the visco-elastic medium so as to create a separation between the medium, and portions of the work piece. The separation is filled with a fluid of less viscosity than the medium, such as air. The separation is preferably maintained in the areas adjacent the inlets. In the preferred embodiment a cyclic motion is imparted by the drive which causes the medium to deform from 50 to 99% and preferably from about 80 to 95%. Deformation recovery rate is generally a function of the speed of cyclic rotation, preferably an orbital rotation.--

Please replace the paragraph beginning on page 5, line 25 with the following rewritten paragraph:

--The preferred visco-elastic abrasive medium is a rheopectic poly(boro-siloxane), filled with viscosity increasing stiffening agents and high loadings of the abrasive of choice, and relatively minor amounts of plasticizers. The preferred poly(boro-siloxane) will have a static viscosity of from about $\eta = 5\ \mathrm{X}\ 10^3$ Centipoise to about $\eta = 5\ \mathrm{X}\ 10^5$ Centipoise. The static viscosity of the formulated medium should be in the range of from about $\eta = 2\ \mathrm{X}\ 10^4$ Centipoise to about $\eta = 8\ \mathrm{X}\ 10^6$ Centipoise.--

Please replace the paragraph beginning on page 6, line 5 with the following rewritten paragraph:

--At the high static viscosities and even higher apparent viscosities under applied strain employed in the present invention, the system may be operated at levels which approach the compressive stress limit, which provide both a fast cutting grinding action and a polishing action on the ground surfaces. The action is attributable to a combination of elastic deformation of the medium and a translation of the work piece surface over the semi-rigid surface of the medium. Elastic deformation is assured by the high levels of applied strain, either compressive or in shear, by the motion imparted. There will be sufficient fluid or plastic flow to provide for conformation of the medium to the surface of the work piece, to provide folding of abrasion debris from the surface into the medium and away from the medium /work piece interface, and to provide the movement of the 30 abrasive within the medium to assure that worn abrasive is removed and fresh abrasive is presented to the working interface. It should be noted that the flow rate is relatively slow and that the elastic

relaxation ratio should be fast enough in the medium used to impart a relaxation of about 1 to 10% for each cycle. Thus, for the apparatus of the preferred embodiment is from about 10 seconds to about 1 ten thousands of a second.--

Please replace the paragraph beginning on page 7, line 3 with the following rewritten paragraph:

--A preferred medium such as poly(boro-siloxane) carrier matrix is adapted particularly to the requirements of the system is also provided. It employs much higher viscosities and loadings of abrasive than are employed in abrasive flow machining in the prior art, in a poly(boro-siloxane) carrier matrix.--

Please replace the paragraph beginning on page 7, line 6 with the following rewritten paragraph:

--Compared to the fluid or plastic extrusion flow which is the basis of U.S. Patent No. 5,125,191, the working rates of the elastic deformation of the present invention are both quite rapid and quite fine, permitting the removal of substantial stock and the attainment of a highly polished surface, in many cases in a single operation with a single medium. Where considerable reduction in roughness is required, it is simple to employ a "roughing" medium followed by a second operation with a "finishing" medium of finer abrasive grit. Rarely will there be occasion to employ more than two media, even to attain the finest surfaces and surface detail and resolution. There is no requirement for sealing the "chamber" in which the operation is performed, and a displacer is optional for a great many forms of work piece, and required only for more complex shapes. In addition, because of the elastic behavior of the medium, the conformate requirements of the displacer, if needed at all, are far less demanding than in our prior work.--

Please replace the paragraph beginning on page 7, line 23 with the following rewritten paragraph:

--Figure 2 is an illustration of the orbital relative rotation between the drive and medium providing the separation between the selected areas of the work piece; and--

Please replace the paragraph beginning on page 8, line 18 with the following rewritten paragraph:

--A displacer (5) is preferably shaped as a complement to the shape of the work piece (1) with a stand-off on the order of three to six millimeters, to define a gap (8) between the displacer (5) and portions of the work piece (1) where the working increment of the media (4) is deposited. Separation (10) is shown in Figure 2 wherein it is defined by a portion of work piece (1) and medium (4) as described in more detail below. The work piece (1), the media (4) and the displacer (5) are all contained within container vessel (6). The displacer (5) and the gap (8) between displacer (5) and the work piece (1) operate to assure that the response of the media to the relative motion drive mechanism and hence the work rate of the abrasive on the surface of the work piece (1) is substantially uniform over the entire surface of the work piece (1) so that at least the selected surface of the work piece to be abraded contacts said abrasive medium under a pressure sufficient to conform said abrasive medium to the surface of the work piece to be abraded, forming a working interface between the work piece and the media.--

Please replace the paragraph beginning on page 9, line 10 with the following rewritten paragraph:

--In the embodiment illustrated in Figure 1, the orbital drive component (3a) and the vertical drive component (3b) serve to engage the work piece (1) with media (4) in a working motion, and create a separation (10) between the media (4) and work piece (1). This imparts a relative repetitive motion between the displacer (5) with its associated work piece (1) and the medium (4) within the chamber (6) at a strain rate sufficient that at least 50% of the deflection of the medium under the conditions of operation occurs by elastic deformation and is elastically recovered, and less than 50% of the deflection of the medium occurs by fluid or plastic flow so that, when said repetitive motion drive actuator is operative and the selected surface of the work piece is in conforming contact with said abrasive medium, the selected surface of the work piece becomes abraded by said abrasive medium as a result of relative movement between said abrasive medium and the selected surface of the work piece.--

Please replace the paragraph beginning on page 9, line 26 with the following rewritten paragraph:

In some cases, no displacer (5) or mandrel is required at all. In others, the requirements of the displacer or mandrel may be needed, but the requirements are greatly simplified in comparison to the highly conforming displacer or mandrel required in our prior patent, United States Patent No. 5,125,191, Rhoades. In the present invention, the mandrel, if employed, should be generally configured to a shape complementary to that of the work piece, with an offset forming a gap (8) between the displacer and work piece of from about 3 to about 6 millimeters. As those of ordinary skill in the art will readily recognize, a displacer providing a gap (8) which is permitted to vary from about 3 to about 6 millimeters is readily and inexpensively produced by undemanding and common techniques.

Please replace the paragraph beginning on page 10, line 12 with the following rewritten paragraph:

--At the high viscosity levels of the media and the high rate of operation of the relative motion drive mechanism preferred in the present invention, the compression and flow of the media during operation are such that the separation (10) formed by the relative motion is maintained through each cycle, and the contact between the work piece (1) and the media (4) is substantially tangential to the path of the driven work piece (1) as the work piece (1) moves within the gap(8). In Figure 1, gap (8) is illustrated as uniform across the cross section, which would be illustrative of the condition when the contact of the orbital motion (3a) is at 90° to the plane of Figure 1 and the linear oscillation (3b) is in the "up" position, see also Figure 3.--

Please replace the paragraph beginning on page 10, line 20 with the following rewritten paragraph:

--A flow of the media into the gap (8), via the conduit (7) from media supply (9), is preferably passed substantially continuously into the gap (8), where it displaces an increment of the media within the gap (8) by fluid or plastic flow, substantially continuously refreshing the working media at the interface with the work piece (1). Media displaced from the stand-off gap (8) carries away heat and machining and polishing debris removed from the surface of the work piece (1). Displacement of the media also assures that fresh, unworn abrasive

particles are brought to the interface. A repetitive motion drive actuator means is connected to at least one of the fixture and the receptacle to impart a relative repetitive motion between the fixture with its associated work piece and the media within the receptacle at a strain rate sufficient that at least 50% of the deflection of the medium under the conditions of operation occurs by elastic deformation and is elastically recovered, and less than 50% of the deflection of the medium occurs by fluid or plastic flow. Therefore, when said repetitive motion drive actuator is operative and the selected surface of the work piece is in conforming contact with said abrasive medium, the selected surface of the work piece becomes abraded by said abrasive medium as a result of relative movement between said abrasive medium and the selected surface of the work piece. The fixture releasably retains the work piece in a manner to prevent relative movement between said fixture and the work piece.--

Please replace the paragraph beginning on page 11, line 10 with the following rewritten paragraph:

--Preferably, the inlets in fluid communication between said chamber and an external reservoir of media is such that the abrasive medium can be selectively injected into and extracted from said chamber while the fixture is in place in the chamber. Even more preferably a second inlet in fluid communication may be included between the chamber and the external reservoir of media so that the abrasive medium can be continuously injected into and extracted from said chamber while the fixture is being worked within the chamber, in a continuous recycle stream.--

Please replace the paragraph beginning on page 14, line 11 with the following rewritten paragraph:

--The work piece is placed in conformal contact with a flowable visco-elastic abrasive medium. It is preferred that the visco-plastic abrasive medium has a static viscosity of from about $\eta = 2 \times 10^4$ Centipoise to about $\eta = 8 \times 10^6$ Centipoise. It is also preferred that the visco-elastic abrasive medium is a rheopectic polymer filled with a particulate solid abrasive, and particularly preferred that the rheopectic polymer is a poly(boro-siloxane).--

Please replace the paragraph beginning on page 15, line 2 with the following rewritten paragraph:

--Expressed in other terms, the present invention provides a method of abrasive working of a contoured work piece with a visco-elastic medium filled with a solid particulate abrasive, comprising the following steps which are to be considered in view of Figures 2 and 3 a-d.--

Please replace the paragraph beginning on page 15, line 7 with the following rewritten paragraph:

--The work piece is then engaged in conformal contact with the visco-elastic abrasive medium, where the medium has a static viscosity of at least about $\eta = 2 \text{ X } 10^8$ Centipoise and an elastic relaxation rate of from about 10 to about 10,000 sec^{-1} at the temperature and strain rate of operation. Like all polymers, the visco-elastic abrasive medium has a relaxation rate which is a nonlinear function of the applied rate of deformation and temperature.--

Please replace the paragraph beginning on page 15, line 12 and extending through line 19 with the following rewritten paragraph:

--The repetitive cyclic relative motion between the work piece and the media is conducted at an amplitude and frequency sufficient that the visco-elastic medium deforms in response to the relative motion in part by fluid or plastic flow to define an intermittent separation between the visco-elastic medium and areas of the work piece not parallel to the direction of the relative motion during a portion of each cycle of the relative motion, the separation being filled with a fluid less viscous than the visco-elastic medium and being displaced from the separation when the separation closes by relative approach of the work piece and the visco-elastic medium.--

Please replace the paragraph beginning on page 15, line 20 with the following rewritten paragraph:

--The visco-elastic medium deforms in response to the relative motion in part by elastic deformation and elastic rebound during each cycle of the relative motion, such that the visco-elastic medium and the areas of the work piece not parallel to the direction of the relative motion come into abrasive working contact during each cycle.--

Please replace the paragraph beginning on page 16, line 1 with the following rewritten paragraph:

--The translational velocity of the relative motion between the visco-elastic medium and areas of the work piece at least substantially parallel to the direction of the relative motion is greater than the relaxation rate of the visco-elastic medium, such that the visco-elastic medium and the areas of the work piece at least substantially parallel to the direction of the relative motion are in abrasive working contact throughout each the cycle.--

Please replace the paragraph beginning on page 16, line 13 with the following rewritten paragraph:

--The apparatus includes means for mounting a work piece on a repetitive motion drive mechanism. Any of the vast array of mechanisms known in the art may be employed, provided that it can reliably and uniformly produce the required power and strain rates dictated by the method of the present invention. The relative motion may be reciprocating linear motion, orbital motion, gyratory motion, rotary motion, or the resultant of a combination thereof. The relative motion may be variable in amplitude and/or in frequency over time.--

Please replace the paragraph beginning on page 16, line 20 with the following rewritten paragraph:

--A visco-elastic abrasive medium is employed in the apparatus. The visco-elastic abrasive medium has a static viscosity of from about $\eta = 2 \times 10^4$ Centipoise to about $\eta = 8 \times 10^6$ Centipoise. The preferred visco-elastic abrasive medium is a rheopectic polymer filled with a particulate solid abrasive, particularly a poly(boro-siloxane).--

Please replace the paragraph beginning on page 20, line 23 with the following rewritten paragraph:

--In typical cases, the micro-finish of the work piece will be improved by as much as a 15:1 reduction in roughness in a single operation with a suitable abrasive grit for the initial condition. (Further polishing generally will not substantially improve the finish once such a level of improvement is attained.) If a less fine surface is acceptable, less processing time is required, enhancing production rates in use. If further polishing, i.e., a further reduction in surface roughness, is required, a further operation of the present invention employing a finer abrasive can provide as much as an additional 5:1 or even 15:1 reduction in roughness. (It

should be noted that it would be possible to start the operation with the finer abrasive medium in the first instance, but the processing time requirements would generally prove excessive and the productivity of the polishing operations would be generally unsatisfactory. It is far more effective and economical to attain reductions in surface finish of magnitudes greater than 20:1 in two or more separate operations with abrasive particle sizes suitable for the conditions.) The final surface roughness can be as little as 0.2 um (or about 0.1 micro-inches) R.. as measured in accordance with ASME B46.1 (1995), SURFACE TEXTURE (SURFACE ROUGHNESS, WAVINESS, AND LAY), 1996, American Society of Mechanical Engineers, New York. While such finely polished surfaces are not typically required of many applications of the present invention, it is sufficient to note that coarser surface polishing consistent with work piece requirements is more readily and rapidly attained.--

Please replace the paragraph beginning on page 21, line 22 with the following rewritten paragraph:

--In addition to the removal of burrs and upset or roiled edges, all edges are gradually radiussed during the operation of the present invention. The extent is generally a function of the time of processing initially proceeding at a quite rapid rate, and gradually slowing as the surface is rounded. If no radiussing of edges is wanted, it is appropriate to employ a protective masking of the edge and the surface immediately adjacent the edge, employing the techniques known in tile abrasive now machining art.--

Please replace the paragraph beginning on page 22, line 24 with the following rewritten paragraph:

--The chamber is not sealed, so that the equipment and its use are far less demanding and complex. In addition, when the separating-filling fluid described above is air, the open chamber permits communication between the separation and the atmosphere as the source of the air. When the separating-filling fluid is a material other than air, it is convenient to employ a liquid which fills the separation and, when displaced, rises above the upper level of the media in the chamber, with the open access to the atmosphere permitting such flow of the fluid without substantial back pressure.--

Please replace the paragraph beginning on page 24, line 25 with the following rewritten paragraph:

Operation of the system causes heating of the media during operation. We prefer to take appropriate steps to limit the temperature rise in the media to avoid temperature higher than about 140°F preferably avoiding media temperatures above about 130°F. In most cases, it is preferable to employ a recirculating flow of the media into and out of the containment chamber, so that increments of media in the gap are displace and replaced by fresh, cooler media. The net flow additionally adds assurance of a substantially uniform distribution of the media and continuous working contact with all the surfaces of the work piece to be worked.

Please replace the paragraph beginning on page 25, line 10 with the following rewritten paragraph:

--The work piece must be engaged by a fixture or tool to place and hold it in conforming contact with the abrasive medium. If the work piece is the driven element of the relative motion drive mechanism, as will often be the most convenient and preferred arrangement, the fixture or tool is preferably a part of the drive mechanism.--

Please replace the paragraph beginning on page 25, line 14 with the following rewritten paragraph:

--While not a requirement of the invention, it is generally effective to provide a mechanism by which the work piece is advanced into the media containment chamber and into its conforming contact with the medium within the chamber from an external mounting station where the work piece is mounted on the fixture or tool. Such an arrangement can greatly facilitate use of the invention by making the mounting and engagement of the work piece faster, simpler and demanding on the machine operator, or in suitable cases permit automation of the operation by such means to permit unattended operation (at least for substantial periods and substantial numbers of parts). In concert, or as an alternative, the containment chamber itself may be adapted to advance toward and retract from the interface with the work piece in its operational position.--

Please replace the paragraph beginning on page 29, line 3 with the following rewritten paragraph:

--It should be noted that some fluid or plastic flow of the abrasive medium is required in the operations of the present invention. While it is not, as in the case of typical abrasive flow machining, the predominant mechanism for performing work on the work piece, it does play an important role in some aspects of the present invention.--

Please replace the paragraph beginning on page 25, line 9 with the following rewritten paragraph:

--In addition, for surface areas which are disposed parallel to the direction of the repetitive motion between the work piece and the medium, fluid or plastic flow assures that there will be a local pressure sufficient to press the medium against the surface to be worked. There may be no component of the motion which is directed into the medium in such areas, and elastic deformation alone may not operate to maintain optimal working contact between the work piece and the medium at the interface. Such flow of the media into the chamber assure such local pressure.--

Please replace the paragraph beginning on page 30, line 3 with the following rewritten paragraph:

--In typical circumstances, the usual ten-fold reduction in surface texture, particularly surface roughness which is typically the primary focus of the operation, can be attained with appropriate selections of conditions and media, within about two to about five minutes of processing time on softer work pieces, such as aluminum and its alloys. For more difficult, i.e., harder, materials, such as steels and the like, the processing time will be correspondingly longer, sometimes ten or even twenty minutes or more.--

Please replace the paragraph beginning on page 31, line 3 with the following rewritten paragraph:

--Surfaces oriented perpendicular or normal to the direction of the relative motion are worked almost exclusively by the elastic deformation and rebound of the media. Surfaces parallel to the direction of the relative motion are worked by elastic deformation and rebound to a far lesser extent because the motion does not impart any substantial compressive force in the direction of the interface between the media and the work piece surface in such regions. The action in such areas is more akin to orbital abrasive flow machining in such areas. The

properties and characteristics of working of surfaces at other angles to the relative motion direction are intermediate between these extremes and show the characteristics of both.--

Please replace the paragraph beginning on page 33, line 5 with the following rewritten paragraph:

--In an alternate embodiment, gel-forming water soluble polymers are formed into hydrogels, with or without gelation promoters such as water soluble salts of metals of Groups III to VIII of the Periodic Table. Hydrogels are based on the formation of intermolecular bonds between the polymer molecules. Such bonds are weaker than ionic bonds and, in the context of the present invention, facilitate thinning of the medium under the high shear stresses imposed in the formation of the polishing jet and providing the sacrificial bonds which protect the covalent bonds of the polymer and minimize chain scission. These hydrogels also serve to promote high viscosity at rest, whether the intermolecular bonds are formed in, makeup of the get or reformed after use, which is highly desirable in preventing settling out of the abrasive particles.--

Please replace the paragraph beginning on page 33, line 15 with the following rewritten paragraph:

--Non-aqueous polymer formulations are also possible where the polymer is cross-linked or gelled by other types of intermolecular bonds. Such formulations are particularly significant to polishing and machining materials which are vulnerable to water, such as ferrous metals and the like.--

Please replace the paragraph beginning on page 35, line 11 with the following rewritten paragraph:

--The hardness of the abrasive should be the highest value consistent with the cost of the materials and the limitations of the work piece, in light of the hardness of the work piece material to be polished. Cutting operations also typically employ the hardest and fastest cutting abrasive available, within cost-effectiveness limits. As a general rule, the harder the abrasive, the faster and more efficient the polishing operation. Limiting the hardness of the abrasive may cost-effective in some cases, since, typically, the harder the material, the more

expensive it is. In addition, the employment of softer abrasives limits the material removal rate, which may be desirable in limited circumstances to facilitate control.--

Please replace the paragraph beginning on page 35, line 19 with the following rewritten paragraph:

--Selection of the abrasive material is not critical in the present invention, and any of the commonly employed materials will be effective. Examples of suitable materials include, for illustration, alumina, silica, garnet, silicon carbide, boron carbide, diamond, and the like. At higher viscosities it may be possible to use tungsten carbide, although its density may pose problems in maintaining effective dispersion in the medium. The reuse of the polishing medium permits economic use of harder, but more expensive abrasives, with resulting enhancements in the efficiency of polishing and machining operations to increase the polishing rate when required. For example, silicon carbide may be substituted in polishing operations where garnet has been used.--

Please replace the paragraph beginning on page 36, line 9 with the following rewritten paragraph:

--Bridging is greatly increased when the critical particulate solids volume concentration of the media formulation is exceeded. Once the critical particulate solids volume concentration is exceeded, the extent of bridging is directly proportion to the extent of excess solids.--

Please replace the paragraph beginning on page 36, line 12 with the following rewritten paragraph:

--The critical particulate solids volume concentration is defined as the concentration of particulate solids at which the volume of the carrier is just sufficient to fill the voids and interstices among the particulate solids particles. When the solids are higher in proportion, the formulation is starved for carrier (polymer base and plasticizer) and voids occur within the mass of the media.--

Please replace the paragraph beginning on page 37, line 9 with the following rewritten paragraph:

--As noted above, the abrasive particles can range from 1 to 2000 micrometers in their major dimension (diameter), preferably from about 20 to 300 micrometers. For surfaces where a fine surface finish is desired, particle sizes of from about 20 to about 100 micrometers are particularly advantageous. It will generally be appropriate to employ the largest particle size consistent with the required polishing and grinding rate and the specified finish characteristics to be attained in the operation.--

Please replace the paragraph beginning on page 37, line 15 with the following rewritten paragraph:

--For a given abrasive particle size, we have also observed that the surface finish of the work piece is rapidly brought to the same or better levels attainable with hand polishing or lapping techniques, but with far less labor and time. When coupled With the ability to use smaller particle sizes, it is ordinarily possible to produce surface finishes which require no hand surface finishing procedures, reducing the number of operations and the amount of labor and equipment required in production. When used to break or radius sharp edges and remove burrs, the technique is rapid effective and readily controlled.--

Please replace the paragraph beginning on page 37, line 22 with the following rewritten paragraph:

--Inelastic fillers, thickeners, plasticizers, lubricants, extenders, diluents and the like may be used in the preferred media of the present invention, much as they have been employed in abrasive flow media of the prior art, but their use should be limited. We prefer to limit the amount of such additives to no more than about 25 weight percent of the media formulation.--

Please replace the paragraph beginning on page 39, line 17 with the following rewritten paragraph:

--In addition, the present invention is free of lay in the working pattern on the work piece surface. Lapping typically produces a surface lay representative of the pattern of motion of the tool which drives the abrasive particles. Indeed, the lay produced in lapping is often employed to develop ornamental patterns on work piece surfaces. In the present invention, we believe, although again we have no wish to be bound thereby, that the combination of resilience in the abrasive medium, the plastic flow of the medium and the lack of any